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THE COMBAT-SYSTEM/SHIP-SYSTEM INTERFACE

BY F. B. FASSNACHT

COMBAT SYSTEMS DEPARTMENT

1 FEBRUARY 1982

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This report describes some of the work being done by the Combat Systems Department of the Naval Surface Weapons Center in the area of combat-system/ship-system design integration.

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FOREWORD

This paper presents an overview of the combat-system/ship-system design integration efforts ongoing at the Naval Surface Weapons Center. The paper was prepared for and presented at a TTCP sponsored Symposium on Ship Combat Systems Survivability Criteria held at the Admiralty Surface Weapons Establishment, Portsdown, Hampshire, England on 2 through 5 November 1981.

BETTY H. GAY
By direction

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THE COMBAT-SYSTEM/SHIP-SYSTEM INTERFACE

INTRODUCTION

This paper addresses several of the things we are doing in the area of combat-system/ship-systems design integration which are relevant to a ship's combat survivability. The topics discussed are: equipment interface analysis, load management and system interaction analysis.

In doing systems integration we have three general goals: 1) to increase system availability, 2) to decrease system vulnerability and 3) to accomplish the first two with overall savings in space, weight and cost. To achieve these goals, we first look for ways to simplify or reduce the onboard equipment. The fewer parts there are, the less there is to get damaged. Also, the more tolerant those parts are to momentary aberrations, the more likely they are to continue working or to rapidly recover from such aberrations. Second, we look for reconfiguration options which can be used to bypass failed equipment and restore full or partial performance. This includes both alternate means for interconnecting equipments and the relocation of equipments to improve the likelihood of having enough equipment left to interconnect. If these two objectives can be achieved with savings in weight, space and cost, these savings can then be spent on redundancy or armoring to further improve combat survivability. In all of this, we take a total ship point-of-view and use mission readiness over time as our primary measure of performance. Since the Naval Surface Weapons

Center is primarily concerned with combat systems, most of our interface work is a joint effort with the Naval Ship Research and Development Center which has ship systems as its primary concern. This assures the total ship point-of-view.

EQUIPMENT INTERFACE ANALYSIS

The objective of a detailed interface analysis is not to determine if the interface will work (though that is certainly the minimum requirement) but rather to determine if it has been optimized from an overall ship mission readiness point-of-view. This is necessary because of the way we design and procure combat equipment. Individual combat equipments are designed as the need or capability becomes evident and funds can be programmed in the Research, Development, Test and Evaluation appropriation. Decisions regarding production and installation of that equipment are made at a later date and are funded from other appropriations. The result is both a management and a time difference between the development and application cycles for combat equipments. This makes it very difficult for the combat equipment designer to foresee all of the interfaces he will have to live with or to examine his design from a total ship point-of-view. Often the integration task is left to the shipbuilder who must interface with an equipment manager who has no funds to alter his equipments.

However, there are some general ground rules which a designer can follow which will lead to fewer equipments and reduce overall vulnerability to both combat damage and peacetime casualties. Based on the equipment interfaces analyses we have done to date, there are four such ground rules we would emphasize. They are:

Standardize data formats. A major illustration of this problem is the encoding of angular data (bearing, elevation, roll, pitch, etc.). The same ship will use 60Hz synchros, 400Hz synchros, analog and digital encoding to transmit angular data from equipment to equipment. This arises because it is easier for the shipbuilder

to provide data convertors than to modify all equipment to a common format. The DD-963, for example, has 2000 lbs of convertors in its Data Processing Center just to handle this problem. Adaption and enforcement of a common format seems an obvious approach. My suggestion is a digital format which is computer compatible and can be generated by digital encoders. This not only eliminates the convertors but would also simplify interfacing with data bus systems currently in development.

Simplify power requirements. Figure 1 gives the three types of power presently specified for shipboard use. Electrical power is generated at 60Hz and converted to 400Hz as required. For type II power, a typical cost for 100KW of conversion capacity is 80 cubic feet, 4500 lbs and $250,000. In addition there is a 14% conversion loss which must be absorbed by the air conditioning and chilled water system. For type III power the costs are even higher because of the tighter tolerances imposed. Unfortunately, combat equipment designers do not have to pay for this conversion. That fact plus horror stories regarding 60Hz power quality have led to a prolifera-tion of 400Hz combat system equipments. The DD-963 class has 600KW of convertors; the CG-47 class has 1200KW of convertors. The Naval Sea Systems Command has recently issued a directive allowing only 60Hz for new equipment design which hopefully will reverse this trend. Concerning power quality there are several problems: switching transients, voltage surges, harmonic distortions and interruptions. Switching transients and interruptions are inherent in a distribution network; they can be minimized but not eliminated. Voltage surges and harmonic distortion originate with the loads placed on the electrical system. While the distribution network can be designed to minimize cross-talk between loads, it cannot eliminate it. Figure 2 shows a typical power profile curve. If such data were available for each load, then some attempts to minimize power quality losses could be taken. One question, is it necessary to maintain rated voltage at the equipment interface during a load surge? Another, can the surge duration be traded for surge peak amplitude? Yet another, can

DOD–STD–1399B

	FREQUENCY	VOLTAGE	DISTORTION	INTERRUPTION
TYPE I	60 Hz ± 3%	440/115V ± 5%	5%	20 s MAX
TYPE II	400 Hz ± 5%	440/115V ± 5%	5%	20 s MAX
TYPE III	400 Hz ± 1/2%	440/200/115V ± 1/2%	3%	3 s MAX

FIGURE 1. SHIPBOARD ELECTRICAL POWER SPECIFICATIONS

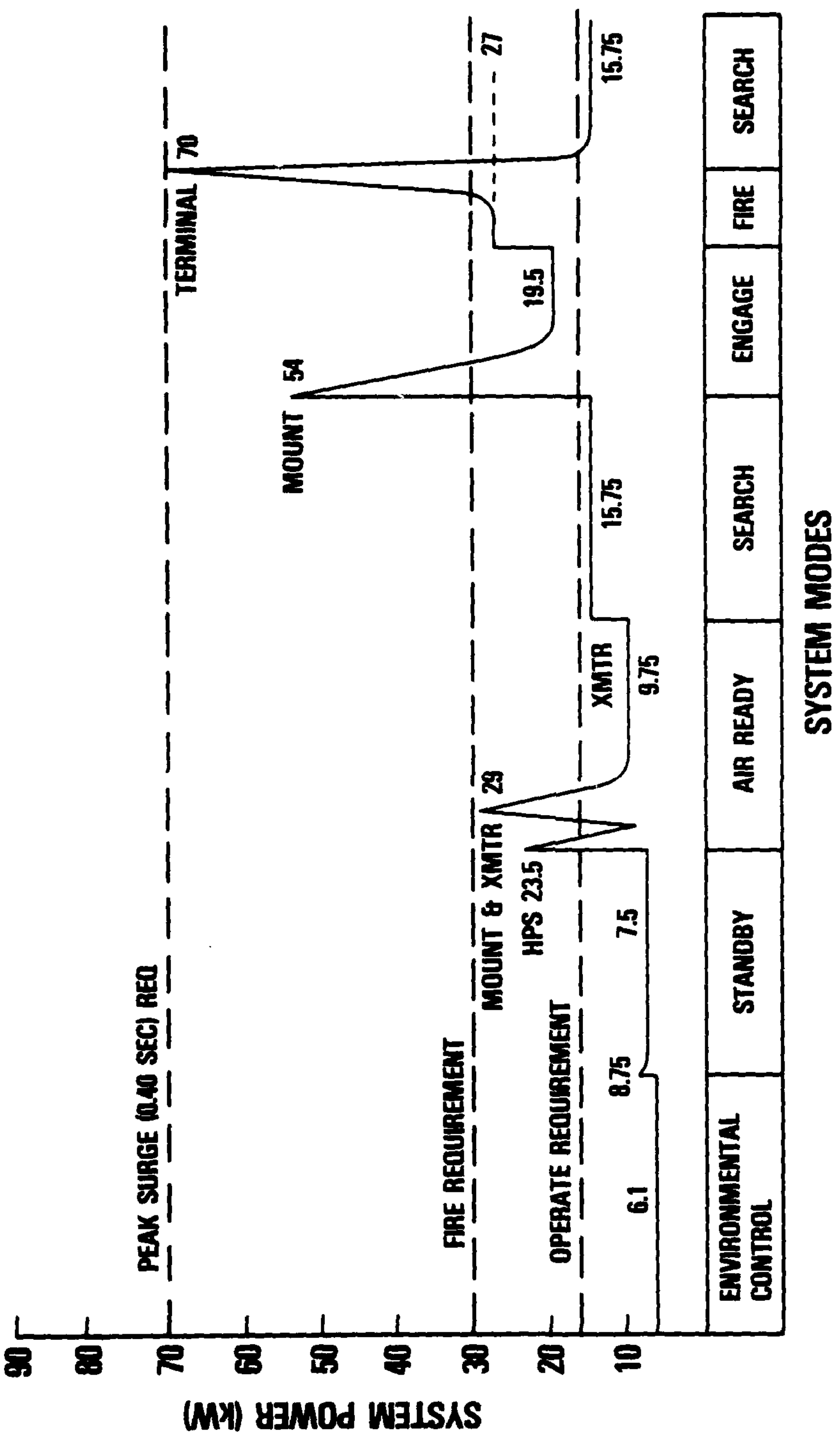


FIGURE 2. TYPICAL POWER PROFILE

equipment be controlled to avoid a coincidence of surge loads?

Design for power interruptions. Referring again to Figure 1, the interruption specification is usually interpreted that the equipment must not be damaged by the interruption, rather than that the equipment must operate during the interruption or even that the equipment must operate immediately following the interruption. Yet these interruption specifications merely reflect the time necessary to reconfigure the electrical distribution system to restore power following battle damage. To illustrate the problem, consider the control circuitry logic diagram for the AN/SPS-40D Radar shown in Figure 3. It includes four time delays as follows: 3/4 min - CRT warm-up, 1/2 min - coolant stabilization, 1 1/2 min - limit filament turn-on surge and 3 1/2 min - transmitter filament warm-up and bias power supply stabilization. All of these time delays have instantaneous reset to zero time upon loss of input. Thus, a momentary loss of 115V 60Hz power will result in a 5 1/2 min delay before the radar is again operational. A momentary loss of 440V 60Hz power or water will result in a 5 min delay. These delays should either be made proportional to interrupt time or be based on a more direct parameter (e.g., filament temperature). An alternate more costly approach would be to install a small battery to maintain power on circuits affecting turn-on delay. For the AN/SPS-40D, such a battery need supply only 1KW vice the normal 32KW full load.

Provide battle shorts. Figure 3 also shows the number of interlock switches in the AN/SPS-40D control circuitry. Of the Start interlocks, twelve are for personnel safety, three for equipment safety and three for sequencing. Of the Antenna Rotate interlocks, two are for personnel safety, five for equipment safety and one for sequencing. Of the Coolant interlocks, all are for equipment safety. Of the Standby interlocks, four are for equipment safety and one for sequencing. Of the High Voltage interlocks, seven are for personnel safety, thirteen for equipment safety and ten for sequencing. In a non-combat situation it makes sense to shut down some or all of the

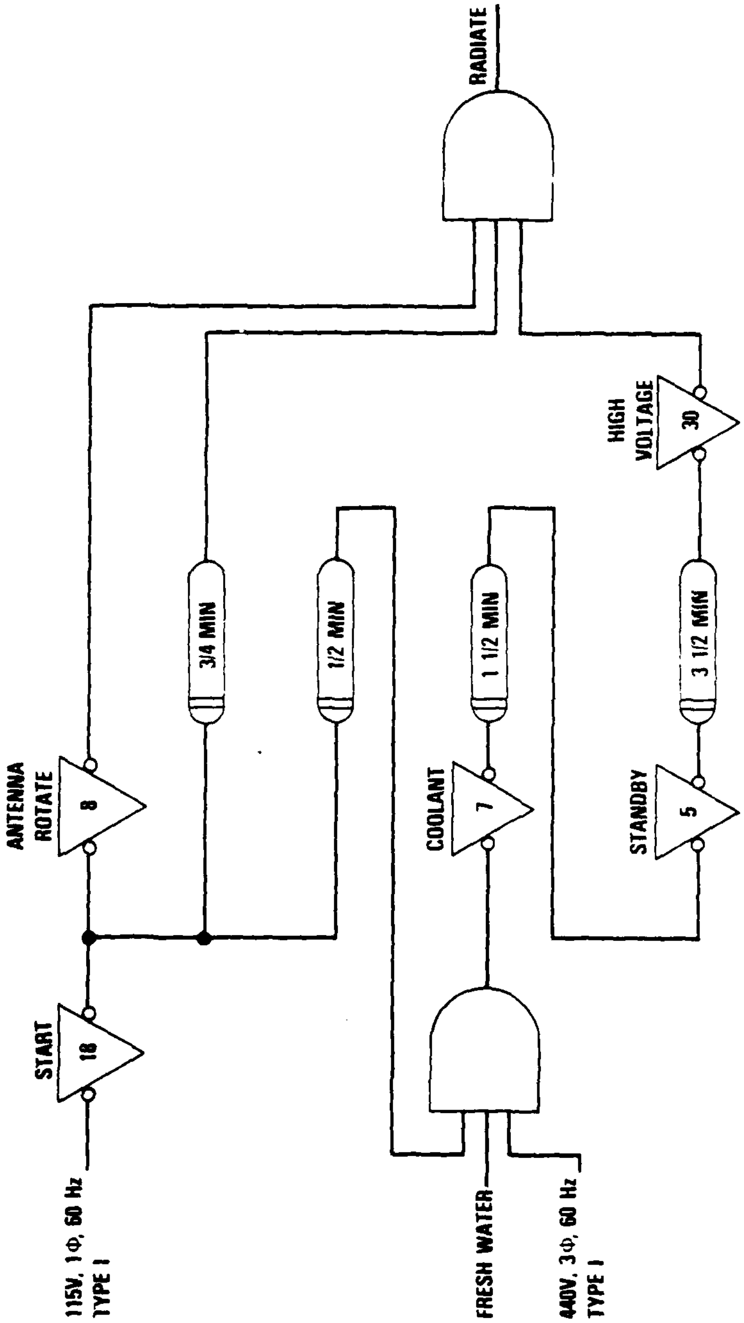


FIGURE 3. AN/SPS-40D AIR SEARCH RADAR CONTROL LOGIC

radar to prevent personnel injury or equipment damage. In a combat situation however, the priority should go to maintaining mission capability. For example, twenty-two of these interlocks are cabinet door switches. If a cabinet door is shocked loose why not turn on an alarm to warn personnel in that compartment rather than shut down the radar? Of the sixty-eight interlocks in the AN/SPS-40D some fifty-three could be switched to sound warning alarms rather than automatically shutting down the radar. This would allow the operator to chose between continuing operation in a less safe condition (which is not necessarily unsafe) or reducing mission capability. A Battle Short switch which reconfigures the control circuitry from its normal configuration to a alternate alarm-only configuration is a command option which sould be provided.

The problem of equipment time delays and interlocks having an adverse effect on mission readiness is not an isolated one. Figure 4 lists the time delays and interlocks for all of the radars on the CGN-36. Note how few interlock bypasses (battle shorts) and proportional timers are listed. When viewed from the point-of-view of restoring mission readiness in a post-hit situation, these figures are not comforting.

LOAD MANAGEMENT

By load management, I mean alternatives for coping with the load shed problem on our newer surface combatants. In terms of survivability, the combat system will not work without electric power and auxiliary services. Anything which can be done to eliminate or shorten power and service outages and to rapidly restore equipments to full capability once the outages are over is a survivability improvement. This topic also provides a good illustration of the advantages of a total ship versus single system point-of-view.

Our newer surface combatants have three gas turbine generator sets. For normal operations two are on-line and the third is in

RADAR	WARFARE FUNCTION	INTERLOCK TOTAL FOR T.D.	TOTAL TIME DELAY—MIN.	INTERLOCK TOTAL FOR OPERATION	TYPE INTERLOCK			
					SAFETY		SERVICE	
					PERS	EQUIP	SEQ	OR
SPS-48A	AAW SEARCH	7[1]	10	40	12	17	4	7
		7[1]	15	59	16	23	5	15
		7[1]	15	72	18	29	5	20
SPS-40D	AAW BACKUP	18	5.5	68	21	32	15	
	SEARCH	25	5.0					
		30	3.5					
SPG-51D	AAW MISSILE ACQUIRE TRACK	21	4.5	37	12	8	14	3
	MISSILE GUIDANCE	11[1]	5[2]	24	7	15	2	
SPG-60	AAW GUNFIRE	11	5[2]	65	27	18	6	4
SPS-10F	ASU SEARCH	4	3	8	4	4		
SPQ-9	ASU	13	3.5					
	GUNFIRE AND BACKUP SEARCH	45	0.5[2]	77	28	36	9	4

[1] BYPASSABLE
[2] PROPORTIONAL TIMER

FIGURE 4. SUMMARY OF INTERLOCKS AND TIME DELAYS FOR CGN-36 RADARS

standby. Should one of the two on-line sets cut off, it is necessary to reduce the total ship electrical load to a value the one remaining set can supply until the standby set can be brought on-line and normal operations restored. If the total load is not reduced within 150 ms, the remaining set will cut off because of turbine overload and the ship will go dark. Having all three gas turbine generator sets on-line would provide a solution. Unfortunately, it would also raise possible short circuit currents above the interrupting capability of available circuit breakers.

This problem is not a new one. Up to now the solution has been to provide a load shed capability within the electrical system which disconnects sufficient loads to prevent the ship from going dark. So long as only non-vital loads were shed, no one was overly concerned. On our newer surface combatants however, the percentage of non-vital to vital loads requires that some vital loads (i.e., combat equipments) also be shed. Thus, what was only an electrical system designer's problem has also become a combat system designer's problem.

Let us now go through some of the design alternatives which can be used to resolve the load shed problem. Figure 5 lists a number of these plotted against a load-shed/load-management scale.

Fixed load shed. Consists of opening a predetermined permanent group of circuit breakers upon receipt of the load shed signal from the electrical plant. These breakers may all be opened at once or in several subgroups depending on the severity of the overload. This is the system presently in use. Since it relies on circuit breakers equipped with remote trip coils, any changes are expensive and require sending the ship to a shipyard.

Power-down capability. This provides an alternate to opening a circuit breaker as a means to reducing loads. The concept is to use or modify an equipment's existing control circuitry to place it

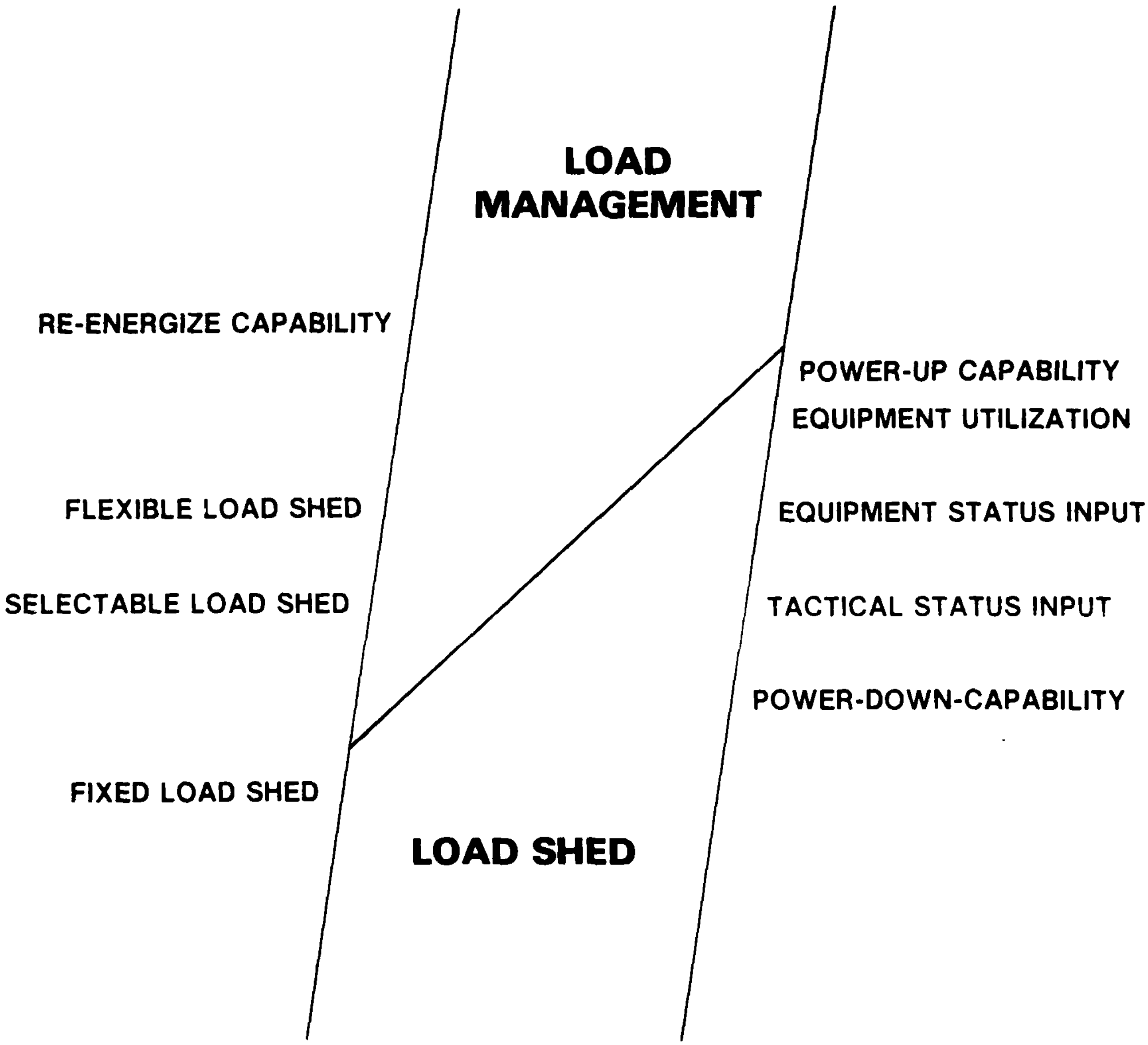


FIGURE 5. LOAD MANAGEMENT DESIGN ALTERNATIVES

in a standby or off condition in response to an external (load shed) signal. This allows for factoring equipment protection, restart and safety into the response to a load shed signal. It also provides for alternates such as inhibiting movement orders to guns, launchers or directors which could reduce the immediate power requirements without introducing restart delays once full generating capacity is restored.

Selectable load shed. This consists of several alternate predetermined menus (groupings) of circuit breakers or equipments with power-down capability with a real time control over which grouping is to be used if a load shed signal occurs. The selection could be made or altered at any time prior to receipt of the load shed signal.

Tactical status input. Having a selectable load shed capability, an obvious choice for tailoring the load shed group is the on-going mission of the ship. A simple AAW, SUW, ASW switch on the Operations Summary Console is one possible implementation. This combination of selectable load shed tailored to on-going mission is the minimal alternate a combat system designer will accept.

Equipment status input. This is an input to the load shed system which indicates which equipments are operable. It allows for a degree of optimization by flagging which capabilities are already out and will not be further reduced if associated equipments are load shed.

Flexible load shed. This requires a load shed controller which is capable of continually updating the load shed menu in response to real-time inputs such as tactical situation, equipment status and electrical plant capacity. As with selectable load shed, the menu could be changed at any time prior to receipt of a load shed signal, but would become frozen upon receipt of the signal and initiation of load shed.

Equipment utilization. Another input which can improve optimization of the load shed menu is data on on-going equipment utilization, i.e., idle, illuminating missile in flight, missile being loaded on rail, etc. This type of input allows for minimal loss of in-use mission capability and may prevent ordnance safety hazards from occurring. It should be remembered that while the load shed menu may be continuously altered to fit conditions, at no time can it total less than the load necessary to be shed to prevent total blackout.

Power-up capability. This is the compliment to the power-down capability discussed earlier. It allows an equipment to automatically cycle from standby or off to full capability in response to an external input. All previous alternatives have addressed the load shedding aspects with little consideration for easing the recovery or restart aspect. They presume a manual restoration of mission capability following restoration of normal generating capacity. This alternative provides for considerating an automatic recovery sequence initiated by removal of the load shed signal.

Re-energize capability. Provide remotely controlled reclosable power control devices to facilitate an automatic recovery sequence once the load shed signal is removed. The controller necessary to implement flexible load shed would likely be adequate to control sequencing of load restoration to accomplish it in a minimum time while assuring that all safety and sequencial requirements are observed.

The above discussion has tried to illustrate the difference between load shed, which is within the purview of the electrical system designer, and load management, which requires the cooperative participation of the designers of all that ship's systems. It was also meant to illustrate that the difference is not clear and subject to local interpretation. For ourselves we chose to define a load management system as one which (a) provides a load shed capability

which adapts to the tactical situation, equipment status and generation capacity and (b) provides for rapid restoration to pre-load status upon removal of the load shed signal.

Now, what is required to implement such a system? Figure 6 provides a potential block diagram for a load management system. The unique equipments are the load management controller, communications link(s) and power controllers. Not explicitly shown are the provision of power-down/power-up capability in user equipments and modifications to combat system and ship systems controls to indirectly effect power-down/power-up actions. The load management controller would consist of an input/output console and a software program which could be configured as stand alone equipments or embedded in existing equipments. The controller would receive generation capacity data and the load shed signal from the electrical plant control equipment. The power controllers would replace existing circuit breakers and incorporate reclose capability. Possibilities are motor driven circuit breakers, magnetic motor controllers and the solid state power controllers now in development. The communications link(s) can be discrete wires as per present practice, a digital data bus or power line carrier wave system both of which are now in development, or a combination of all three.

SYSTEM INTERACTION ANALYSIS

We have two motives for system interaction analysis. The first is to understand how the various systems aboard ship interact with each other and how far a casualty in any one system cascades into other systems. The second is to provide a uniform means of assessing the value of proposed design changes regardless of which system they are in. The value scale used is Mission Readiness versus Time. This measurement scale is the same as that used by the Fleet to report unit readiness to the FLTCINCs and CNO. As shown in Figure 7 there are five levels, M1 through M5. The first four are defined relative to the ship's designed capability by

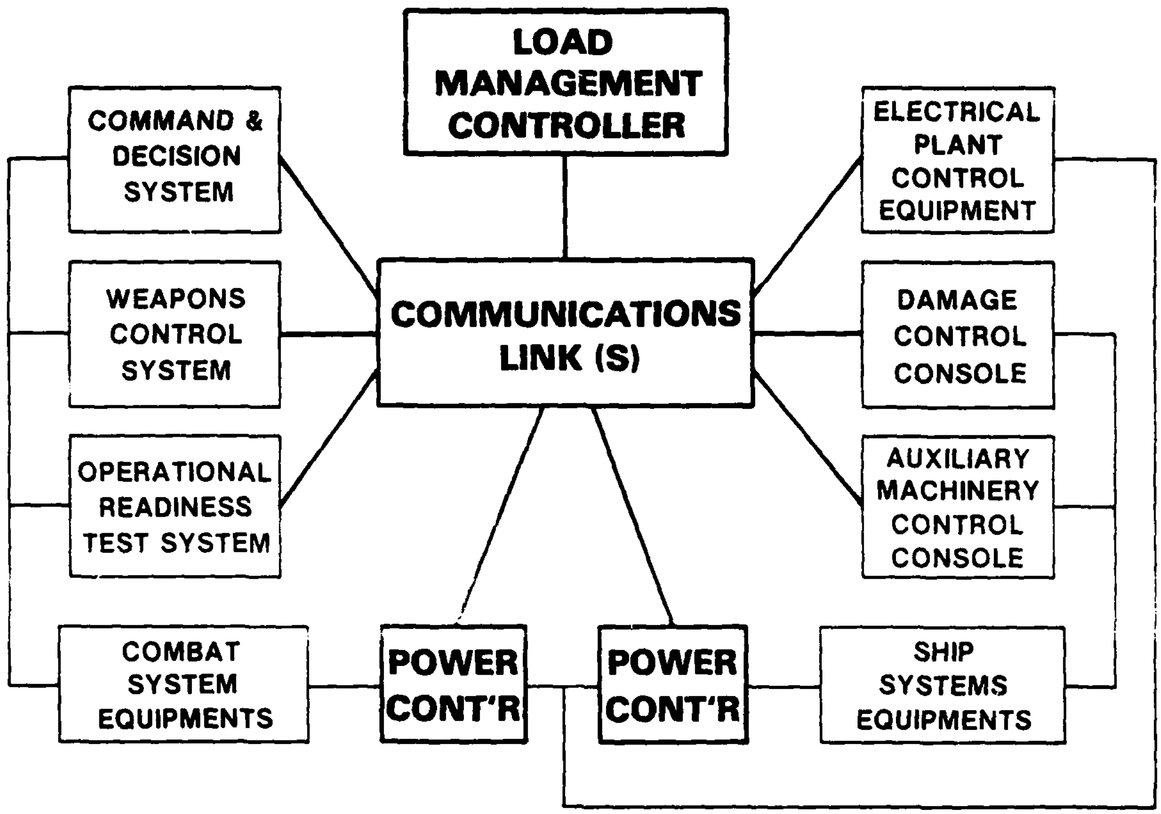
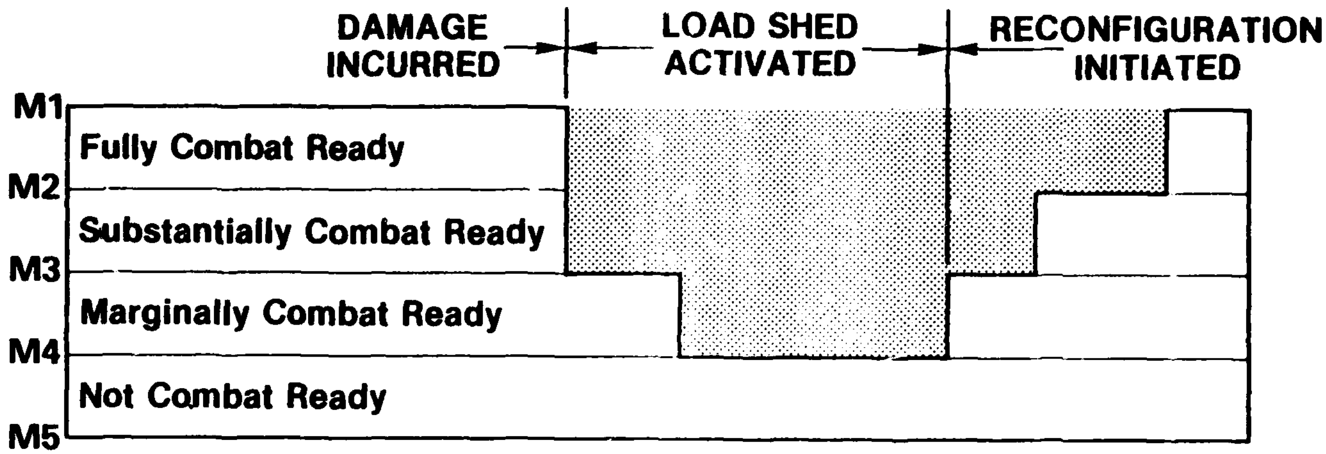


FIGURE 6. LOAD MANAGEMENT SYSTEM BLOCK DIAGRAM



- WARFARE AREAS
- REQUIRED OPERATIONAL CAPABILITIES

FIGURE 7. MISSION READINESS VERSUS TIME

OPNAVINST C3501.66 "Unit Status and Identity Report" and various supplemental Type Commander instructions. The fifth, M5, denotes zero capability. What is of interest is the extent to which the readiness is degraded and the length of time this degradation persists. Such data is computed for each of the ship's warfare areas and required operational capabilities. Figure 8 gives the primary warfare areas and required operational capabilities for the CG-47. They are typical of most surface combatants. The overall picture presented by such a family of mission readiness versus time plots presents the impact of design changes in terms Fleet personnel are familiar with and can readily form a judgement from.

To generate these plots we use a computerized systems interaction model. These models are written for a specific ship and their details vary depending on the type of analysis to be performed. Referring to Figure 9, common sections of all models are the ship systems functional logic, combat system functional logic and mission readiness assessment logic. The other sections depend on the specifics of a given analysis. Thus, for a reliability or survivability analysis, an initial conditions section which inputs equipment mode as a function of time is added. For analysis of a load shed or load management proposal, load shed sequence and power summary sections are added.

To understand how the model works, let us go through some of the logic used. First, there is the logic to relate individual functions to a given required operational capability. Figure 10 shows such a logic diagram for the CG-47 to engage air targets using surface-to-air armament. The left leg consists of those functions needed to use AAW missiles. The right leg consists of those functions available for point defense. For point defense, two independent options are available, CIWS to engage and destroy and ECM to deceive and deflect. The M numbers above each block specify the maximum loss that function can cause in that leg. Thus for the CDS-MISSILE-SUPV function, an input of M1 through M4 will

REQUIRED OPERATIONAL CAPABILITIES STATUS   Ø.Ø MINUTES   CONDITION I HOT   LOADSHED OFF

ANTI-AIR WARFARE	M5
PROVIDE ANTI-AIR DEFENSE FOR A CONVOY (MILITARY OR MERCENTILE)	5
PROVIDE ANTI-AIR DEFENSE FOR A TASK FORCE	5
PROVIDE ANTI-AIR DEFENSE OF AN AMPHIBIOUS OPERATION	5
PROVIDE ANTI-AIR DEFENSE OF A GEOGRAPHICAL AREA	5
ENGAGE AIR TARGETS IN COOPERATION WITH OTHER FORCES	5
DETECT, IDENTIFY AND TRACK AIR TARGETS	5
CONTROL COMBAT AIR PATROL	5
ENGAGE AIR TARGETS USING SURFACE-TO-AIR ARMAMENT	5
CONDUCT ELECTRONIC WARFARE AGAINST AIR TARGETS	5
ANTISUBMARINE WARFARE	M5
SCREEN A CONVOY (MILITARY OR MERCANTILE)	5
SCREEN A TASK FORCE	5
OPERATE AS AN ASW BARRIER UNIT	5
SCREEN AN AMPHIBIOUS LANDING AREA	5
CONDUCT AIR OPERATIONS IN SUPPORT OF AIRBORNE ANTISUBMARINE OPERATIONS	5
ENGAGE SUBMARINES IN COOPERATION WITH OTHER FORCES	5
CONTROL AIRCRAFT INVOLVED IN ANTISUBMARINE OPERATIONS	5
DETECT, LOCATE, CLASSIFY AND TRACK SUBMARINES	5
ENGAGE SUBMARINES WITH ANTISUBMARINE ARMAMENT	5
DISENGAGE, EVADE AND AVOID SUBMARINE ATTACK	5
CONDUCT ELECTRONIC WARFARE AGAINST SUBSURFACE TARGETS	5
CONDUCT ACOUSTIC WARFARE AGAINST SUBSURFACE TARGETS	5
SURFACE WARFARE	M5
CONDUCT SURFACE RECONNAISSANCE	5
ENGAGE SURFACE TARGETS WITH ANTISURFACE ARMAMENT (EXCLUDING NAVAL GUNFIRE SUPPORT)	5
ENGAGE SURFACE TARGETS IN COOPERATION WITH OTHER FORCES	5
CONDUCT NAVAL GUNFIRE SUPPORT	5
DETECT, IDENTIFY AND TRACK SURFACE TARGETS	5
CONDUCT ELECTRONIC WARFARE AGAINST SURFACE TARGETS	5
PROVIDE SURFACE DEFENSE FOR A TASK FORCE AGAINST FAST PATROL BOATS OR SURFACE RAIDERS	5
COMMAND AND CONTROL	M5
PROVIDE COMMAND AND CONTROL FACILITIES FOR A TASK FORCE COMMANDER AND STAFF	5
COORDINATE AND CONTROL OPERATIONS OF THE TASK FORCE TO CARRY OUT ASSIGNED MISSIONS	5
PROVIDE OWN UNITS COMMAND AND CONTROL FUNCTIONS	5
MOBILITY	M5
STEAM TO DESIGNED CAPABILITY	5
REPAIR ENGINEERING CASUALTIES	5
CONTROL DAMAGE	5
MANEUVER IN FORMATION	5
PERFORM SEAMANSHIP, AIRMANSHIP AND NAVIGATION TASKS	5
REPLENISH AT SEA	5
MAINTAIN THE HEALTH AND WELL-BEING OF THE CREW	5
OVERALL SHIP READINESS	C5

FIGURE 8. TYPICAL SYSTEMS INTERACTION MODEL OUTPUT

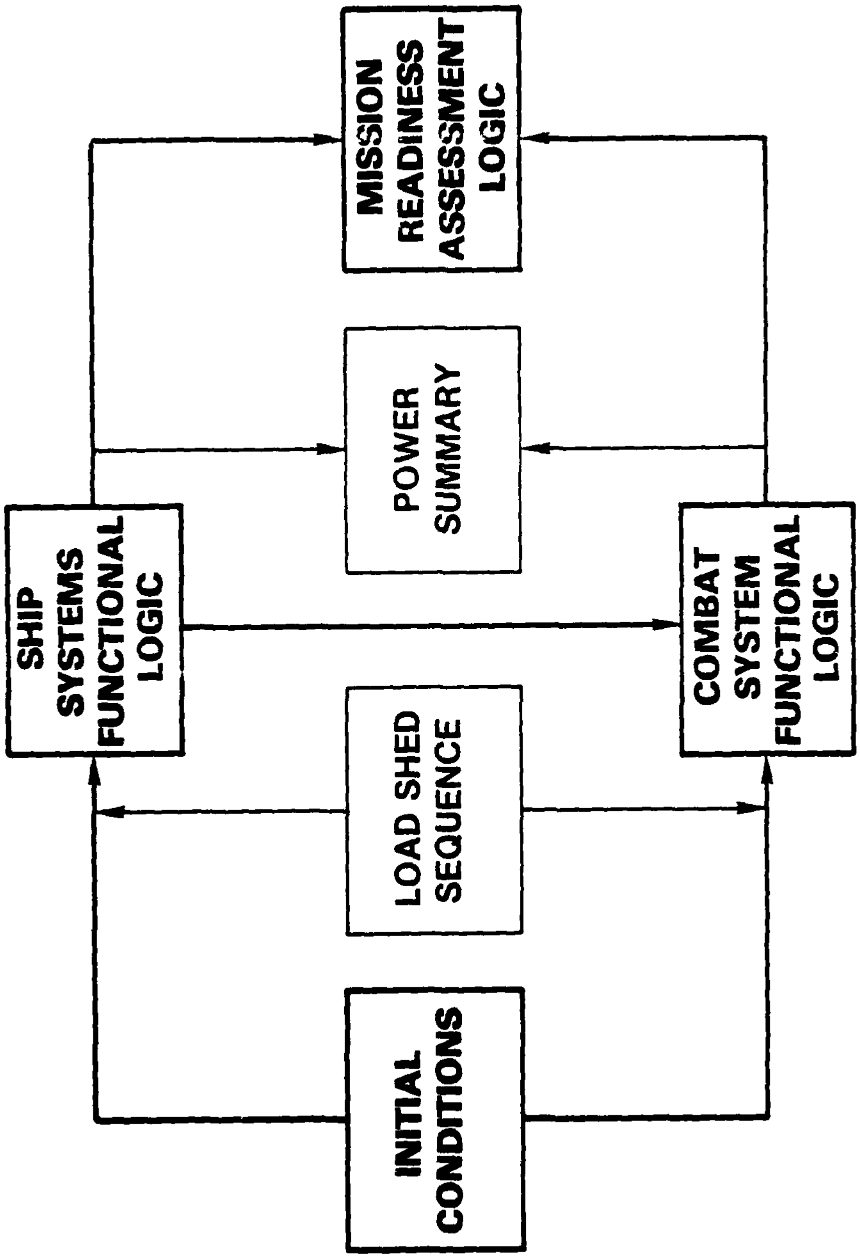


FIGURE 9. SYSTEMS INTERACTION MODEL

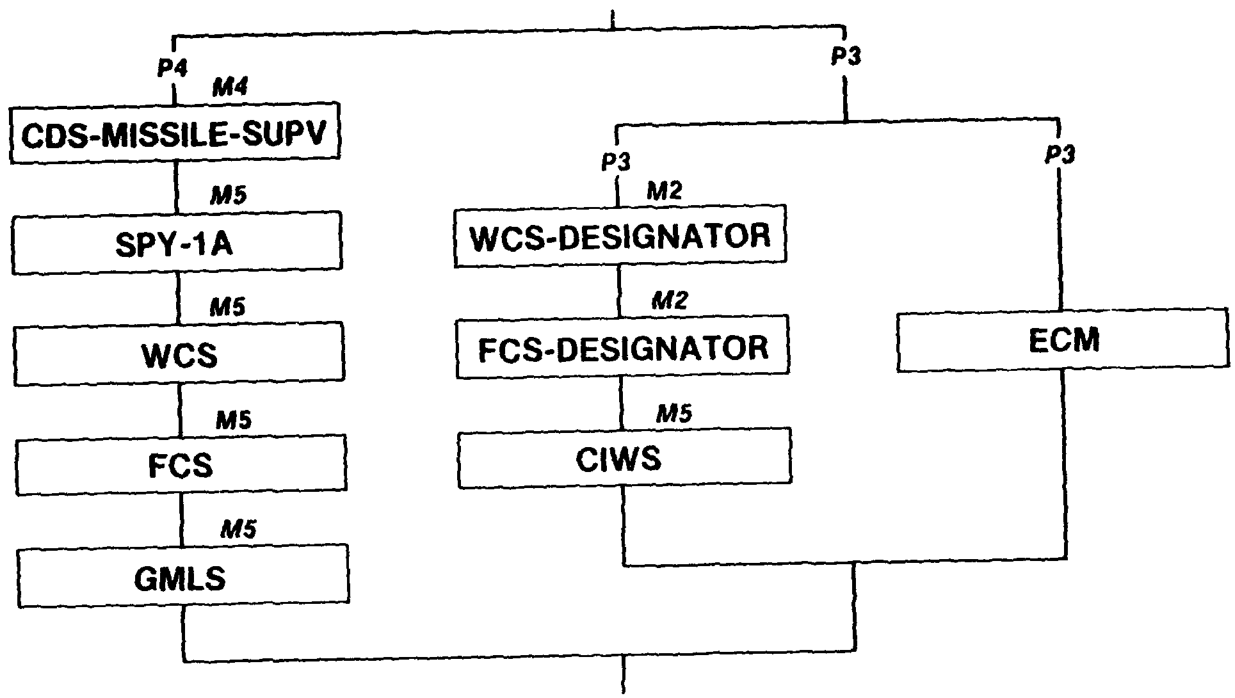


FIGURE 10. LOGIC DIAGRAM—ENGAGE AIR TARGETS USING SURFACE-TO-AIR ARMAMENT

cause a corresponding loss in that leg, but an input of M5 will only cause a loss of M4 in the leg. The final value of the leg is equal to the worse loss from the series functions in that leg. For junctions, the P numbers below each junction specify the loss to the junction if that leg is M5 and the other leg(s) is M1. The junction loss increases to M5 if all legs are M5. For intermediate leg values, the junction loss is proportional to these limits.

Next, for each function in Figure 10, there is another logic diagram similar to that for the Guided Missile Launching System shown in Figure 11. This diagram details the various equipments making up the function and the support services required for each of those equipments. The significance of the M and P numbers is the same as for Figure 10. Not shown on Figure 11, but an essential part of the computer coding, is the time delay associated with changes in the inputs to each equipment. In turn, each of these inputs has its own logic diagram in the ship systems functional logic.

The primary output of the model is a listing of readiness levels, of which Figure 8 is an example, for each point in time that a change in equipment or circuit mode occurs. From these listings, graphs such as that in Figure 7 can be prepared. Overall, the systems interaction model provides a linkage between the status of each equipment and the ship's mission readiness. By including all ship systems in the model, any secondary or cascading effects are also identified. It is this cross-coupling which is both necessary to having an adequate model and provides the most useful output of the model.

CONCLUSION

There are many ways to go about improving the combat survivability of our ships. This paper has focused on one of these ways which should receive greater attention, namely, improving the design integration of the various "systems" aboard ship into a single

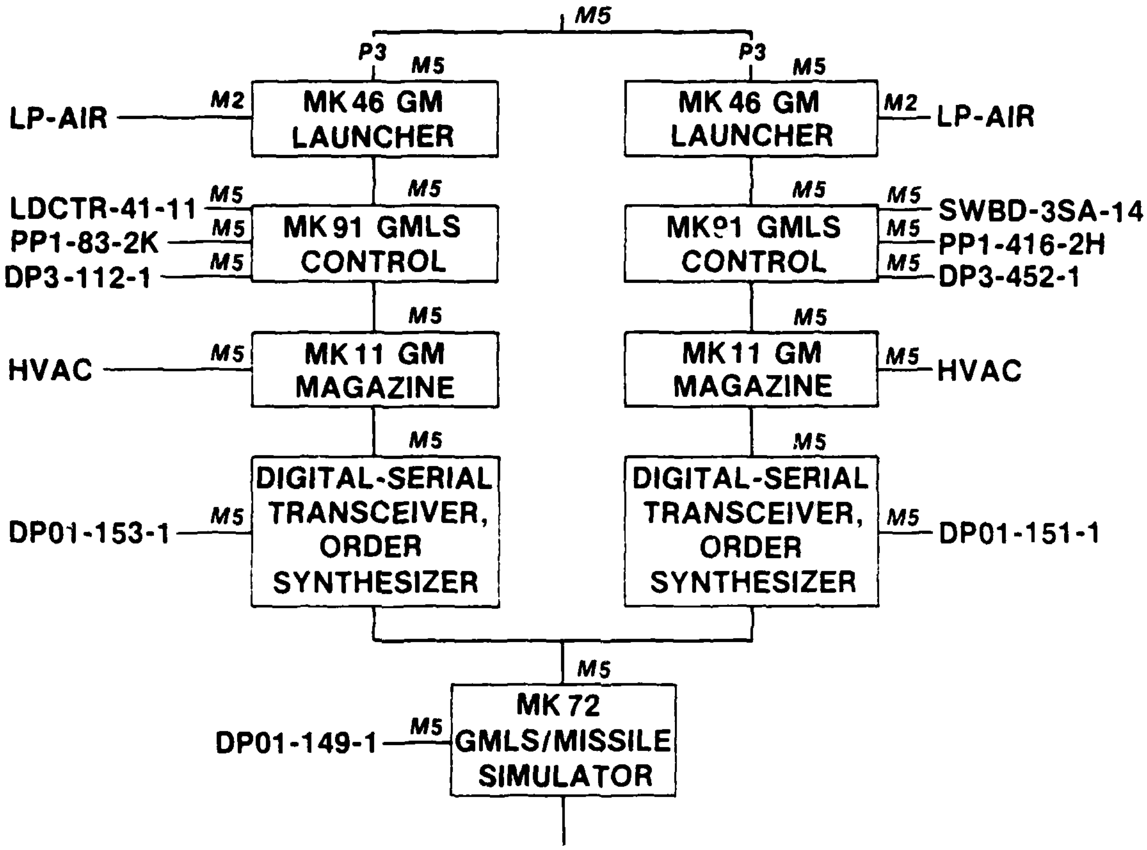


FIGURE 11. LOGIC DIAGRAM—MK 26 GUIDED MISSILE LAUNCHING SYSTEM

"ship system". Many of the improvements identified by this route will be low cost and, if identified early enough in the development cycle, easy to implement.

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